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The influence of age and maturity status on the maximum and explosive strength characteristics of elite youth female soccer players

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20 **Abstract**

21
22 Research has characterised the strength characteristics of elite youth male soccer
23 players, although little is known about female players. This study investigated
24 the influence of age and maturity status on strength characteristics in 157 female
25 soccer players (U16; $n=46$, U14; $n=43$, U12; $n=38$, U10; $n=30$), recruited from
26 three elite female soccer academies. Linear mixed models were used to
27 determine the difference by age or maturation. **Peak force (PF)** was *possibly* and
28 *likely* greater for older age groups, however relative **PF** was *most likely trivial*
29 between consecutive age groups. Relative impulse at 100 and 300 ms was *very*
30 *likely* greater at U12 than U10, *likely* and *possibly* less at U12 than U14, and
31 *most likely* less and *possibly* greater at U16 than U14. Relative **PF** was *likely* less
32 at Pre **peak height velocity (PHV)** than Circa and Circa than Post-PHV.
33 Relative Impulse at 100 and 300 ms was *most likely* lower for Pre-PHV than
34 Circa and Pre-PHV than Post-PHV, and *possible* greater at Circa than Post-PHV.
35 Age and maturation impact upon PF and impulse, thus practitioners should
36 account for individual maturation status when comparing players. These data
37 provide **reference** strength data for elite youth female soccer players, which can
38 be used when monitoring player development.

39

40 Key words: soccer, youth, maturation, strength

41

42 **Introduction**

43

44 The popularity and professionalism of female soccer has increased markedly in
45 recent years, with elite senior players now employed on either a professional or
46 semi-professional basis. The increased professionalism has resulted in the growth
47 of elite female soccer academies for youth players (9-16 years), designed to
48 develop the next generation of elite senior International players (Wright and
49 Lass, 2016). As part of the training programme, youth elite female soccer players
50 now regularly undertake strength and conditioning training and scheduled fitness
51 testing throughout the season to monitor their development.

52

53 During a match, senior level female soccer players have been reported to cover
54 approximately 10 km, with 1.7 km completed at high-speed running ($>18 \text{ km} \cdot \text{h}^{-1}$;
55 Datson et al., 2014). A match also consists of explosive actions such as sprints,
56 jumps, tackling and change of direction (COD), that appear to determine the
57 outcome of games (Mohr et al., 2008). Given the relationships between strength
58 and athletic performance (Suchomel, Nimphius and Stone. 2016), it is important
59 that strength training is included within a player's development programme (Le
60 Gall et al., 2010).

61

62 While research has characterised the strength characteristics of elite youth male
63 soccer players (Deprez et al., 2015; Comfort et al., 2014; Philippaerts, et al.,
64 2006; Gissis et al., 2006), little is known about the strength characteristics of
65 youth female players. Findings from studies including youth male athletes may
66 not be transferable to female athletes, especially during maturation, given the

67 differences in the timing and tempo and their differences in physical and
68 physiological characteristics from the onset of puberty (Lloyd and Oliver, 2012).
69 Vescovi et al. (2010) investigated lower body power characteristics via a
70 countermovement jump (CMJ), observing improvements with age (Under 12s
71 (U12) and U13 had lower CMJ heights than U17–U21) in United States female
72 soccer players. While findings from this study provide comparative data for
73 youth female soccer players, the authors did not consider the influence of
74 maturation on performance, which has been shown to significantly influence the
75 performance of youth male soccer players (Lovell et al., 2015). As such less is
76 known about the maximum and explosive strength qualities of young females
77 soccer players during different stages of maturation (Wright and Laas, 2016).
78 The Football Association (FA) have recently highlighted the need for female
79 soccer players to improve their “athleticism” (Campbell, 2017), thus the
80 quantification of strength characteristics within youth female soccer players can
81 provide practitioners with data to compare players against, informing specific
82 interventions.

83

84 The assessment of strength in young athletes can be somewhat problematic in
85 comparison to senior athletes. Young athletes may not have an appropriate
86 training age, as such traditional strength testing methods (i.e. one repetition
87 maximum) may not be safe. The isometric mid-thigh pull (IMTP) is an alternate
88 strength assessment method, which has been reported to be both a safe and
89 reliable (ICC = 0.95, CV = 4%) strength assessment with low measurement error
90 (Haff et al., 2015; Dos Santos et al., 2016), and has a strong correlation with
91 dynamic performance (Stone et al., 2004; McGuigan et al., 2010).

92

93 Therefore, the purpose of this study was to quantify the strength characteristics
94 of elite youth female soccer players (i.e., U10, U12, U14 and U16) using the
95 IMTP, while considering maturation status of players. Such information is
96 important to aid the design of strength and conditioning programmes for this
97 cohort to enhance the “athleticism” of players, as highlighted by the FA.
98 Furthermore, such data can be used as reference data when assessing the
99 effectiveness of training interventions and monitoring player development.

100

101 Methods

102 The purpose of this study was to determine the IMTP characteristics of elite
103 youth female soccer players from U10 - U16 and investigate the influence of age
104 and maturation on strength characteristics. Anthropometric (standing height,
105 sitting height, body mass and leg length) and IMTP characteristics were collected
106 following preseason in September, which was the start of the 2016-2017 season.
107 Players from three elite female soccer academies were familiarised with the
108 IMTP prior to the commencement of the study.

109

110 Subjects

111 157 female soccer players (U16; $n = 46$, U14; $n = 43$, U12; $n = 38$, U10; $n = 30$)
112 were recruited from three elite Tier 1 female soccer academies in England.
113 Subjects were considered elite, as they were part of a Tier 1 Regional Talent
114 Centre, which is the highest standard of female youth club soccer in England. All
115 three academies trained for approximately 36 weeks per year. U16 and U14
116 players completed approximately six hours of field based soccer training and

117 approximately two hours of strength and conditioning sessions per week. U12
118 and U10 players completed approximately four hours of field based soccer
119 training and approximately one hour of strength and conditioning per week. Prior
120 to participating in the study, institutional ethics approval was gained and players
121 and their parents/guardians provided assent/consent. Age categories were defined
122 by chronological age on the 1st September 2016, which established their status
123 for competition and training squads.

124

125 Procedures

126 All testing was carried out at the start of the 2016 season. Testing was conducted
127 a minimum of 48 hours post competitive match play or training at each
128 respective academy. On arrival subjects completed anthropometric assessments
129 prior to undertaking a standardised warm up before completing the IMTP test.
130 The standardised warm up consisted of dynamic stretching, followed by 3 IMTP
131 efforts at individual perceived increasing intensities (50, 70 and 90% maximum
132 efforts) with 1-minute rest between repetitions.

133

134 Anthropometry

135 Subjects standing height (cm) and sitting height (cm) were recorded to the
136 nearest 0.1cm using a 132 Seca Alpha stadiometer following the standard
137 protocol outlined by Ross et al., (1991). Body mass was measured on a
138 commercially available portable force platform (AMTI, ACP, Watertown, MA)
139 using a sampling rate of 1000 Hz then multiplied by 9.81 to convert to kg. Body
140 mass was taken to be BWg^{-1} (kg) with g = acceleration due to gravity.

141

142 Age and Maturity Offset

143 Chronological age was calculated as the difference between date of birth and the
144 date of assessment. To estimate maturity status, age at peak height velocity
145 (PHV) was calculated using the Mirwald et al. (2002) equation. The Mirwald
146 equation has been reported to be a reliable ($R^2= 0.91$, $SEE=0.50$), non-invasive
147 practical solution for the measure of biological maturity (Mirwald et al., 2002).
148 Years from PHV was calculated for each subjects by subtracting the age at PHV
149 from chronological age. Subjects were also classified into 3 pre-defined groups;
150 Pre-PHV (offset < -1 years), Circa-PHV ($\leq \pm 1$ years) or Post-PHV (offset $> +1$
151 years) in relation to their years from PHV (YPHV), which is consistent with
152 previous literature (Cunha et al., 2015; Hammami et al., 2016).

153

154 Isometric Mid-Thigh Pull

155 The IMTP was performed on a commercially available portable force platform
156 (AMTI, ACP, Watertown, MA) with a sampling rate of 1000 Hz, which is
157 consistent with previous methodologies (Dos'Santos et al., 2016; Haff et al.,
158 2015). Subjects performed the IMTP on a customized pull rack, in a self-selected
159 position similar to that of the second pull of a power clean, with a flat trunk
160 position and their shoulders in line with the bar (Haff et al., 2015). Research has
161 previously demonstrated that differences in knee and hip joint angles during the
162 IMTP do not influence kinetic variables (Comfort et al., 2015), justifying the
163 self-selected preferred mid-thigh position.

164

165 Prior to commencement of the testing, subjects were given two practice trials.

166 Consistent with previous methodologies (Dos'Santos et al., 2016), subjects were

167 instructed to pull as “fast and hard” as possible, and received loud, verbal
168 encouragement. Each subject completed two trials lasting 5 seconds, with 3-5
169 minutes of rest between each trial, which is consistent with previous literature
170 (Dos’Santos et al., 2016).

171

172 The highest peak force (PF) achieved over the 2 trials was considered the
173 subjects best trial. PF was identified as the maximum force value obtained during
174 the best trial of the IMTP. In addition to highest PF, relative (to body mass) PF
175 and impulse were also measured at time specific force values (100 and 300 ms).
176 The vertical force–time curve was integrated over 100 and 300 ms windows from
177 the onset of contraction (when the vertical force increased above a threshold of
178 40 N) to calculate measures of impulse. Net impulse allows quantification of the
179 mechanism that underpin movement (Mundy et al., 2016) Impulse at 100 and
180 300 ms was chosen as this was consistent with previous values used in the
181 literature and used because these are consistent with similar ground reaction
182 times for sprinting, various jumps and change of direction (Weyand, Lin, Bundle,
183 2006). Relative values were calculated using the ratio scaling method (i.e.
184 Impulse / body mass; Jacobsen, 2013). The reliability data from the two maximal
185 trials for the measured variables can be seen for each respective age group in
186 Table 1.

187

188 *****Table 1 near here *****

189

190 **Statistical Analyses**

191 A linear mixed model was used to determine the difference between age or
192 maturation group (each defined as a fixed factor), while accounting for potential
193 differences between academies (defined as a random factor). Magnitude based-
194 inferences were used to assess for practical significance (Hopkins et al., 2009).
195 The threshold for a difference to be considered practically important (the
196 smallest worthwhile difference; SWD) was set at 0.2 x between subject standard
197 deviation (SD), based on Cohen's *d* effect size (ES) principle. The probability
198 that the magnitude of difference was greater than the SWD was rated as <0.5%,
199 *almost certainly not*; 0.5-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%, *possibly*;
200 75-95%, *likely*; 95-99.5%, *very likely*; >99.5%, *almost certainly* (Hopkins et al.,
201 2009). Where the 90% Confidence Interval (CI) crossed both the upper and
202 lower boundaries of the SWD ($ES \pm 0.2$), the magnitude of difference was
203 described as *unclear* (Hopkins et al., 2009). ES were rated as *trivial* (<0.2), *small*
204 (0.2-0.59), *moderate* (0.6-0.19) *large* (1.2-1.99) or *very large* (2.0-4.0) (Hopkins
205 et al., 2009).

206

207 **Results**

208 Table 1 presents the anthropometric and IMTP characteristics by annual age
209 category. Height and body mass was *most likely* to *possibly* greater in older age
210 groups. PF was *possibly* and *likely* greater for older age groups, however
211 differences in relative PF were *most likely trivial* between consecutive age
212 groups. Impulse (100 and 300 ms) was *very likely* and *most likely* greater for U12
213 than U10, and *likely* greater for U16 than U14. The difference in impulse
214 between U12 and U14 was *possibly trivial* at 100 ms and *most likely greater* at
215 U14 at 300 ms. Relative impulse at 100 and 300 ms was *very likely* greater at

216 U12 than U10, *likely* and *possibly* less at U12 than U14, most *likely* and *possibly*
217 greater at U16 than U14.

218

219 *****Table 2 near here*****

220

221 Table 2 presents the anthropometric and IMTP characteristics for each maturity
222 off-set group. Height and body mass were *very likely* to *possibly* greater for more
223 mature players. Peak force was *most likely* to *very likely* greater for more mature
224 players. However, relative PF was *likely* less at Circa-PHV and Post-PHV than
225 Pre-PHV. Impulse at 100 ms was *likely* greater at Pre-PHV than Circa-PHV and
226 *likely greater* at Post-PHV than Pre-PHV. Impulse at 300 ms was *possibly* and
227 *likely* greater for more mature players. Relative impulse at 100 and 300 ms was
228 *most likely* lower at Circa-PHV than Pre-PHV and most likely lower Post-PHV
229 than Pre-PHV.

230

231 *****Table 3 near here*****

232

233 **Discussion**

234 The purpose of this study was to investigate the influence of age and maturation
235 on strength characteristics, and provide reference force-time data for youth
236 female soccer players. Findings suggest maturation influences absolute PF in
237 youth female soccer players but has less effect on relative PF and impulse.
238 Therefore, when absolute measures of IMTP strength are evaluated and used to
239 compare between athletes of the same age, practitioners should account for
240 maturation status of individual athletes when evaluating strength qualities. These

241 data provide reference strength data for elite youth female soccer players, which
242 can be used when monitoring player development.

243

244 **Influence of Age on Peak Force and Impulse**

245 To the authors knowledge this is the first study to provide strength data for youth
246 female athletes by annual age groups using the IMTP. Findings suggest that
247 absolute PF is greater in older player, which is consistent with previous literature
248 demonstrating an increase in absolute strength of knee strength extensors (143%)
249 and flexors (131%) until the age of 14 years when strength was observed to
250 plateau (De Ste Croix et al., 1999). However, when PF was made relative to
251 body mass differences were *most likely trivial* between consecutive age groups,
252 highlighting the influence of body mass on absolute peak force. These findings
253 demonstrate that when body mass is considered, performance in maximal
254 strength qualities are similar between consecutive age groups and should be
255 considered when making comparisons between youth athletes of different sizes.

256

257 While PF is a good indicator of maximum strength, it does not provide
258 information about the explosive qualities of the athlete. As such, net impulse
259 provides data on the force-time characteristics, useful for practitioners looking to
260 prescribe individual strength programmes (i.e. force vs. velocity development).

261 This study demonstrates that both absolute and relative impulse at 100 and 300
262 ms increased from U10 to U12. Although it is not possible to determine from this
263 study the specific mechanism for this improvement, this is potentially due to the
264 development of neurological factors associated with children of this
265 chronological age, where development of the neuromuscular system naturally

266 accelerates due to increased myelination and motor unit synchronization (Malina,
267 2004), which are associated with improvements in explosive force production in
268 children (Lloyd et al., 2011). In contrast, differences in impulse at 100 ms were
269 possibly trivial between U12-U14s and likely decreased between age categories
270 when made relative to body mass. Between U14 and U16, female soccer players
271 experience greater absolute and relative impulse at 100 and 300 ms. Training age
272 and specifically strength training age, in addition to chronological age could
273 explain the differences in performance, which unfortunately were not quantified
274 in this study.

275

276 The development of muscular strength is multi-faceted and underpinned by
277 hormonal, muscular, neural, and mechanical factors (De Ste Croix, 2015) and
278 confounded by factors such as body mass and stature (Ford et al., 2011).
279 Between the ages of 11-14 years represented by these annual age categories
280 (U12-U14s) females are experiencing a period of accelerated physical
281 development evidenced by the large increase in body mass and stature in the
282 present study. Females have also been reported to experience an increase in fat
283 mass around peak weight velocity (Ford et al., 2011), which may explain why
284 relative measures decreased, due to the non-functional role of fat for athletic
285 performance. It is not possible to determine the specific mechanisms for the
286 observed difference between age groups in this study. Therefore, further research
287 should investigate the influence of lean body mass development on the strength
288 characteristics of youth female soccer players, which was not collected in this
289 study.

290

291 Beyond the age of 16 years players do not remain in a FA soccer academies in
292 England, which are defined as development environments. As such, strength
293 changes into adulthood within this population is unclear and warrants further
294 investigation, given that previous research has demonstrated that female athletes
295 continue to demonstrate improvements in physical performance until 21 years
296 (Vescovi et al., 2011).

297

298 **Influence of Maturation on Peak Force and Impulse**

299 Findings of this study show that maturation impacts upon the development of
300 both PF and impulse in elite youth female soccer players. PF and impulse were
301 greater in more mature players, which is consistent with observations in youth
302 male soccer players, where maturation status has been observed to be a strong
303 indicator of physical performance (Lloyd et al., 2015; Buchheit and Mendez-
304 Vilanueva, 2013; Vandendriessche et al., 2012). These changes can be attributed
305 to the normal development of strength resultant from growth and maturation.
306 During this time there are marked changes in the central nervous system and
307 morphological changes of the muscle including muscular, neural and mechanical
308 factors resulting in an increase in muscular strength (Malina, 2004; Ford et al.,
309 2011).

310

311 When PF and impulse were made relative to body mass, findings show that PF
312 and impulse at 100 and 300 ms were lower at Circa-PHV in comparison to Pre-
313 PHV. Furthermore, even when body mass is accounted for, relative impulse 100
314 and 300 ms and relative PF were lower Post-PHV in comparison to Pre-PHV,
315 suggesting that a strength deficit develops in youth female soccer players. These

316 finding are consistent with previous literature which has reported that female
317 adolescents experience a significant regression in hip abduction strength relative
318 to body mass in the year they transition from pre-pubertal to pubertal status and a
319 decrease in relative strength from pre-post maturation (Quatman-Yates et al.,
320 2013). These observations are important for practitioners, who should
321 acknowledge there is potentially a decrease in performance, despite the increase
322 in maturation status.

323

324 Given that the findings of this study show that relative strength was greatest Pre-
325 PHV, the most beneficial time to initiate neuromuscular integrative training
326 programs may be during pre-adolescence, prior to the period of pubertal
327 maturation when youths are growing most rapidly (Myer et al., 2011), which
328 may also attenuate the decrease in strength during PHV. It is recommended that
329 youth female soccer players regularly undertake a structured and progressive
330 strength and conditioning programme that aims to develop the neuromuscular
331 system Pre-PHV and Circa-PHV and targets both neural and morphological
332 changes Post-PHV for both a performance improvement and as an injury
333 prevention strategy. Noteworthy, it is only in recent years that the prevalence of
334 supplementary strength training in youth female soccer academies has increased,
335 in addition research has reported that compliance of female soccer players to
336 neuromuscular training programs can be low (Rubley et al., 2011; Wright and
337 Lass, 2016). Therefore, there is a need for continued education for both players,
338 coaching staff and parents within female soccer academies to develop a culture
339 and compliance to strength development, given the relationship with improved
340 physical performance and reduce injury risk factors when implemented

341 successfully.

342

343 Future studies should evaluate strength development longitudinally, as a
344 limitation of this study was the cross-sectional design. Furthermore, monitoring
345 of other anthropometric and physical qualities may be advantageous to develop a
346 greater understanding of the development trajectories of youth female soccer
347 players. A further limitation of this study is that strength variables were
348 expressed relative to body mass, whereas future studies should explore strength
349 relative to lean mass or allometrically scaled. This study also found varying
350 levels of within reliability for measures by age group. For example, impulse at
351 100 ms for U10 players may be erroneous given the within session reliability
352 ($ICC = 0.711$, $CV = 13.8\%$), which may be attributed to their limited training
353 age, and should be a consideration when interpreting findings from young
354 players. A further limitation of this study was not having information on the
355 specific training age, or strength training age of the players, or information on the
356 menstrual cycle of players, which may have impacted the observed findings.
357 Finally, it is not possible to determine from this study the specific mechanism for
358 the differences observed, therefore future research should look to consider the
359 above limitations when evaluating the strength characteristics and longitudinal
360 development in female soccer players.

361

362 In conclusion, the present study presents reference IMTP force-time
363 characteristics of elite youth female soccer players aged between 9-16 years by
364 both annual age group and maturation status. Findings suggest that a strength
365 deficit may develop in youth female soccer players. It is recommended that youth

366 female soccer player regularly undertake a structured and progressive strength
367 and conditioning programme that aims to develop the neuromuscular system Pre-
368 PHV and Circa-PHV and targets both neural and morphological changes Post-
369 PHV.

370

371 **Practical Applications**

372 Findings of this study provide reference data for English youth female soccer
373 players by annual age category and maturation groups. It is recommended that
374 such data should be used by strength and conditioning coaches and other
375 practitioners working with youth players when assessing individual player's
376 strengths and weaknesses, as well as monitoring longitudinal player
377 development. Given that relative strength was lower in Post-PHV players, it is
378 important that youth female soccer players are regularly undertaking structured
379 strength training as part of their weekly training structure to maximise
380 longitudinal physical development, given the known relationship between strength
381 and explosive activities (e.g., sprint ability, Sanders et al., 2013), and injury risk
382 (Suchomel, Nimphius, and Stone, 2016).

383

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